EPA Region 6

Human Health

Medium-Specific Screening Levels

U.S. Environmental Protection Agency
Region 6
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BACKGROUND ON REGION 6 SCREENING VALUES

General

Screening levels are chemical concentrations that correspond to fixed levels of risk (i.e., either a one-in-one million [10^{-6}] cancer risk or a non-carcinogenic hazard quotient of one, whichever occurs at a lower concentration) in soil, air, and water. In most cases, where a substance causes both cancer and non-cancer or systemic effects, the 10^{-6} cancer risk will result in a more stringent criterion and consequently this value is presented in the table. Screening level concentrations based on cancer risk are indicated by "C." Screening level concentrations based on non-carcinogenic health threats are indicated by "N."

In general, screening level concentrations in the table are risk-based but for soil there are two important exceptions: (1) for several volatile chemicals, screening levels are based on the soil saturation equation ("sat") and (2) for relatively less toxic inorganic and semi-volatile contaminants, a non-risk based "ceiling limit" concentration is given as 10^{+5} mg/kg ("max").

The screening value table also presents information on soil for both residential and industrial exposure scenarios and including and excluding the dermal exposure pathway. The exposure pathways used in developing the screening values are indicated in ***boldface italics*** on the exposure table below.

TYPICAL EXPOSURE PATHWAYS BY MEDIUM FOR RESIDENTIAL AND INDUSTRIAL LAND USES

EXPOSURE PATHWAYS, ASSUMING:		
MEDIUM	RESIDENTIAL LAND USE	INDUSTRIAL LAND USE
Ground Water	***Ingestion from drinking***	Ingestion from drinking
	Inhalation of volatile chemicals	Inhalation of volatile chemicals
	Dermal absorption from bathing	Dermal absorption
Surface Water	***Ingestion from drinking***	Ingestion from drinking
	Inhalation of volatile chemicals	Inhalation of volatile chemicals
	Dermal absorption from bathing	Dermal absorption

EXPOSURE PATHWAYS, ASSUMING:		
MEDIUM	RESIDENTIAL LAND USE	INDUSTRIAL LAND USE
	Ingestion during swimming	
	Ingestion of contaminated fish	
Soil	***Ingestion***	***Ingestion***
	Inhalation of particulates	***Inhalation of particulates***
	Inhalation of volatile chemicals	***Inhalation of volatile chemicals***
	Exposure to indoor air from soil gas	Exposure to indoor air from soil gas
	Exposure to ground water contaminated by soil leachate	Exposure to ground water contaminated by soil leachate
	Ingestion via plant, meat, or dairy products	Inhalation of particulates from trucks and heavy equipment
	Dermal absorption	***Dermal absorption***

Toxicity Values

EPA toxicity values, known as non-carcinogenic reference doses (RfD) and carcinogenic slope factors (SF) were obtained from IRIS, HEAST, and EPA's National Center for Environmental Assessment, NCEA. The IRIS and NCEA values were updated as of May 1, 1999. The HEAST values were not reviewed since HEAST has not been updated since the last screening value table. The priority among sources of toxicological constants used are as follows: (1) IRIS (indicated by "i"), (2) HEAST ("h"), (3) NCEA ("n"), and (4) withdrawn from IRIS or HEAST and under review ("x").

Route-to-route extrapolations ("r") were frequently used when there were no toxicity values available for a given route of exposure. Oral cancer slope factors ("SFo") and reference doses ("RfDo") were used for both oral and inhaled exposures for organic compounds lacking inhalation values. Inhalation slope factors ("SFi") and inhalation reference doses ("RfDi") were used for both inhaled and oral exposures for organic compounds lacking oral values unless the toxicity data indicated otherwise. An additional route extrapolation is the use of oral toxicity values for evaluating dermal exposures. **Although route-to-route methods are a useful**

screening procedure, the appropriateness of these default assumptions for specific contaminants should be verified by a toxicologist.

Inorganic Background

Naturally-occurring inorganic background levels may be considered in the screening of environmental data. Background values are important in making risk-based decisions. Elevated naturally-occurring background, relative to risk-based screening levels, and/or widespread contaminant concentrations can complicate the determination of a cleanup level or the extent of the corrective action effort. The issues are complex and present a challenge for regulators nationwide. Typical values of inorganic concentrations found in soils within Region 6 are described in the table below. The values have been compiled from technical sources and from Region 6 approved background study reports.

Contaminant	Background Concentration/ Range mg/kg		Contaminant	Background Concentration/ Range mg/kg
Aluminum	45000		Lead	10-18
Arsenic	1.1-16.7		Manganese	389-850
Barium	430		Mercury	0.1
Beryllium	0.5-2		Nickel	16
Boron	2-100		Selenium	0.2
Cadmium	0.01-1.0		Silver	0.01-5
Chromium	38		Tin	122
Cobalt	8		Vanadium	66
Copper	20		Zinc	22-50

Dermal

Since these screening levels are intended as an initial risk-based screen of environmental media, the screening level concentrations reflect the inclusion and exclusion of the dermal exposure route. Site soil concentrations should be screened against both the “with dermal” and “without dermal" numbers. A chemical-specific decision whether this exposure route is relevant should be made in subsequent risk assessment efforts.

APPLICATION OF THE SCREENING LEVELS TABLE

The decision to use the screening levels at a site will be driven by the potential benefits of having generic risk-based concentrations in the absence of site-specific risk assessments.

Potential Benefits:

- Screening sites to determine further evaluation
- Prioritizing multiple sites within a facility
- Focusing future risk assessment efforts

Developing a Conceptual Site Model

The primary condition for use of the screening levels is that exposure pathways of concern and conditions at the site match those taken into account by the screening levels. Thus, it is always necessary to develop a conceptual site model (CSM) to identify likely contaminant source areas, exposure pathways, and potential receptors. This information can be used to determine the applicability of screening levels at the site and the need for additional information.

The final CSM diagram represents linkages among contaminant sources, release mechanisms, exposure pathways and routes and receptors based on historical information. It summarizes the understanding of the contamination problem.

As a final check, the CSM should answer the following questions:

- Are there potential ecological concerns?
- Is there potential for land use other than those covered by the screening levels (i.e., residential and industrial)?
- Are there other likely human exposure pathways that were not considered in development of the screening levels (e.g. raising beef, dairy, or other livestock)?
- Are there unusual site conditions (e.g. large areas of contamination, high fugitive dust

levels, potential for indoor air contamination)?

Potential Problems

As with any risk-based tool, the potential exists for misapplication. In most cases the root cause will be a lack of understanding of the intended use of the screening levels table. In order to prevent misuse of screening levels, the following should be avoided:

- ! Applying screening levels to a site without adequately developing a conceptual site model that identifies relevant exposure pathways and exposure scenarios,
- ! Not considering background concentrations when choosing screening levels,
- ! Use of screening levels as cleanup levels without the consideration of other relevant criteria
- ! Use of screening levels as cleanup levels without verifying numbers with a toxicologist/risk assessor,
- ! Use of outdated screening levels tables that have been superseded by more recent publications,
- ! Not considering the effects from the presence of multiple chemicals.

TECHNICAL SUPPORT DOCUMENTATION

The Region 6 screening levels consider human exposure hazards to chemicals from contact with contaminated soils, air, and water. The emphasis of the screening levels equations and technical discussion are aimed at developing initial goals for soils, since this is an area where few standards exist. For air and water, additional reference concentrations or standards are available for many chemicals (e.g. non-zero MCLGs, AWQC, and NAAQS) and consequently the discussion of these media are brief.

Inhalation of Volatile Chemicals and Fugitive Dusts

Agency toxicity criteria indicate that risks from exposure to some chemicals via inhalation far outweigh the risk via ingestion; therefore soil screening levels have been designed to address this pathway as well. The models used to calculate screening levels for inhalation of volatile chemicals / particulates are updates of risk assessment methods presented in RAGS Part B (USEPA 1991a) and are consistent with the *Soil Screening Guidance: User's Guide and*

Technical Background Document (USEPA 1996a,b).

To address the soil-to-air pathways the screening level calculations incorporate volatilization factors (VF_s) for volatile contaminants and particulate emission factors (PEF) for nonvolatile contaminants. These factors relate soil contaminant concentrations to air contaminant concentrations that may be inhaled on-site. The VF_s and PEF equations can be broken into two separate models: an emission model to estimate emissions of the contaminant from the soil and a dispersion model to simulate the dispersion of the contaminant in the atmosphere.

It should be noted that the box model in RAGS Part B has been replaced with a dispersion term (Q/C) derived from a modeling exercise using meteorological data from 29 locations across the United States because the box model may not be applicable to a broad range of site types and meteorology and does not utilize state-of-the-art techniques developed for regulatory dispersion modeling. The dispersion model for both volatile chemicals and particulates is the AREA-ST, an updated version of the Office of Air Quality Planning and Standards, Industrial Source Complex Model, ISC2. However, different Q/C terms are used in the VF and PEF equations. Los Angeles was selected as the 90th percentile data set for volatile chemicals and Minneapolis was selected as the 90th percentile data set for fugitive dusts (USEPA 1996 a,b). A default source size of 0.5 acres was chosen for the screening level calculations. This is consistent with the default exposure area over which Region 6 typically averages contaminant concentrations in soils. If unusual site conditions exist such that the area source is substantially larger than the default source size assumed here, an alternative Q/C could be applied (see USEPA 1996a,b).

Volatilization Factor for Soils

Volatile chemicals, defined as those chemicals having a Henry's Law constant greater than 10^{-5} (atm-m^3/mol) and a molecular weight less than 200 g/mole, were screened for inhalation exposures using a volatilization factor for soils (VF_s).
The emission terms used in the VF_s are chemical-specific and were calculated from physical-chemical information obtained from a number of sources including *Superfund Exposure Assessment Manual* (SEAM, EPA 1988), *Subsurface Contamination Reference Guide* (EPA 1990a), *Fate and Exposure Data* (Howard 1991), and *Superfund Chemical Data Matrix* (USEPA 1994c). In those cases where Diffusivity Coefficients (Di) were not provided in existing literature, Di's were calculated using Fuller's Method described in SEAM. A surrogate term was required for some chemicals that lacked physico-chemical information. In these cases, a proxy chemical of similar structure was used that may over- or under-estimate the screening level for soils.

The soil saturation concentration “sat” corresponds to the contaminant concentration in soil at which the absorptive limits of the soil particles, the solubility limits of the soil pore water, and saturation of soil pore air have been reached. Above this concentration, the soil contaminant may be present in free phase, i.e., nonaqueous phase liquids (NAPLs) for contaminants that are liquid at ambient soil temperatures and pure solid phases for compounds that are solid at ambient soil temperatures.

Equation 10 below is used to calculate “sat” for each volatile contaminant. As an update to RAGS HHEM, Part B (USEPA 1991a), this equation takes into account the amount of contaminant that is in the vapor phase in soil in addition to the amount dissolved in the soil’s pore water and sorbed to soil particles. A basic principle of the volatilization model is not applicable when free-phase contaminants are present. How these cases are handled depends on whether the contaminant is liquid or solid at ambient temperatures. Liquid contaminant that have a volatilization factor (VF)-based PRG that exceeds the “sat” concentration are set equal to “sat” whereas for solids (e.g., PAHs), soil screening decisions are based on appropriate other pathways of concern at the site (e.g., ingestion and dermal contact).

Volatilization Factor for Tap Water

For tap water, an upper bound volatilization constant (VF_w) is used that is based on all uses of household water (e.g showering, laundering, and dish washing). Certain assumptions were made. For example, it is assumed that the volume of water used in a residence for a family of four is 720 L/day, the volume of the dwelling is 150,000 L and the air exchange rate is 0.25 air changes/hour (Andelman in RAGS Part B). Furthermore, it is assumed that the average transfer efficiency weighted by water use is 50 percent (i.e. half of the concentration of each chemical in water will be transferred into air by all water uses). Note: the range of transfer efficiencies extends from 30% for toilets to 90% for dishwashers. Volatilization was only included in the tap water equations for compounds with an “1" in the “VOC” column.

Particulate Emission Factor for Soils

Inhalation of chemicals adsorbed to respirable particles (PM_{10}) were assessed using a default PEF equal to 1. 316 x 10^9 m^3/kg that relates the contaminant concentration in soil with the concentration of respirable particles in the air due to fugitive dust emissions from contaminated soils. The generic PEF was derived using default values in Equation 11, which corresponds to a receptor point concentration of approximately 0.76 ug/m^3. The relationship is derived by Cowherd (1985) for a rapid assessment procedure applicable to a typical hazardous waste site where the surface contamination provides a relatively continuous and constant potential for emission over an extended period of time (e.g. years). This represents an annual average emission rate based on wind erosion that should be compared with chronic health criteria; it is not appropriate for evaluating the potential for more acute exposures.

With the exception of specific heavy metals, the PEF does not appear to significantly affect most soil screening levels. Equation 11 forms the basis for deriving a generic PEF for the inhalation pathway. For more details regarding specific parameters used in the PEF model, the reader is referred to *Soil Screening Guidance: Technical Background Document* (USEPA 1996a).

Note: the generic PEF evaluates windborne emissions and does not consider dust

emissions from traffic or other forms of mechanical disturbance that could lead to greater emissions than assumed here.

Dermal Default Values

Much uncertainty surrounds the determination of hazards associated with skin contact with soils. One important data gap is the lack of EPA verified toxicity values for the dermal route. For screening purposes it is assumed that dermal toxicity values can be route-to-route extrapolated from oral values but this may not always be an appropriate assumption and should be checked.

The Supplemental Dermal Guidance to RAGS is not yet available, but several aspects of the guidance have been presented at various conferences. The dermal assumptions used in developing the screening values are based upon the latest information available as of May 6, 1999. Chemical-specific dermal absorption values for contaminants in soil and dust are presented for arsenic, cadmium, chlordane, 2,4-D, DDT, lindane, PAH's, pentachlorophenol, PCBs, and dioxin. Otherwise, default skin absorption fractions are assumed to be 0.10, for organic chemicals. A default absorption for inorganics is no longer recommended.

Default values for dermal contact with soil include surface area and soil adherence. Exposed surface areas are 5700 and 2900 for adults and children, respectively. Recommended adherence factors are age-specific adherence factors of 0.07 and 0.2 mg/cm^2 for adults and children, respectively. An adult soil adherence factor of 0.2 is also used in the industrial exposure scenario.

SSLs for the Migration to Groundwater Pathway

Development of Soil Screening Levels

In May 1996 the EPA Office of Solid Waste and Emergency Response published the Soil Screening Guidance: Technical Background Document (Document 9355.4-17A, PB96-963502, EPA/540/R-95/128, available through NTIS at 703-487-4650). This document provides (1) a framework in which soil screening levels are to be used, (2) a detailed methodology for calculating soil screening levels, and (3) generic soil screening levels for selected chemicals.

The methodology for calculating SSLs for the migration to groundwater was developed to identify chemical concentrations in soil that have the potential to contaminate groundwater. Migration of contaminants from soil to groundwater can be envisioned as a two-stage process: (1) release of contaminant in soil leachate and (2) transport of the contaminant through the underlying soil and aquifer to a receptor well. The SSL methodology considers both of these fate and transport mechanisms.

SSLs are back calculated from acceptable ground water concentrations (i.e. nonzero MCLGs, MCLs, or risk-based screening levels). Residential exposure scenarios are assumed based on a fixed upper bound risk of 10^{-6} or a fixed hazard quotient of 1. First, the acceptable groundwater concentration is multiplied by a dilution factor to obtain a target leachate concentration. For example, if the dilution factor is 10 and the acceptable ground water concentration is 0.05 mg/L, the target soil leachate concentration would be 0.5 mg/L. The partition equation (presented in the *Soil Screening Guidance* document) is then used to calculate the total soil concentration (i.e. SSL) corresponding to this soil leachate concentration.

The SSL methodology was designed for use during the early stages of a site evaluation when information about subsurface conditions may be limited. Because of this constraint, the methodology is based on conservative, simplifying assumptions about the release and transport of contaminants in the subsurface. These SSLs provide reasonable maximum estimates of transfers of contaminants from soil to other media. One column contains soil concentrations protective of groundwater quality; the other contains soil concentrations protective of air quality.

Users of the screening levels table are strongly encouraged to consult the official guidance document for details concerning the soil screening calculations. Currently, the Region 6 spreadsheet does not generate values based upon the soil screening calculations. The numbers for the "DAF" column are pasted from the August 1998 Region 6 Medium-Specific Screening Level document. Based upon the feedback from the spreadsheet users and the regional resources, future revisions to the spreadsheet can incorporate the information necessary to calculate appropriate soil values for protection of groundwater.

Exposure Factors

Default exposure factors were obtained primarily from RAGS Supplemental Guidance Standard Default *Exposure Factors* (OSWER Directive, 9285.6-03) dated March 25, 1991 and more recent information from U.S. EPA's Office of Solid Waste and Emergency Response, and U.S. EPA's Office of Research and Development.

Because contact rates may be different for children and adults, carcinogenic risks during the first 30 years of life were calculated using age-adjusted factors ("adj"). Use of age-adjusted factors are especially important for soil ingestion exposures, which are higher during childhood and decrease with age. However, for purposes of combining exposures across pathways, additional age-adjusted factors are used for inhalation and dermal exposures. These factors approximate the integrated exposure from birth until age 30 combining contact rates, body weights, and exposure durations for two age groups - small children and adults. Age-adjusted factors were obtained from RAGS PART B or developed by analogy.

For soils only, non-carcinogenic contaminants are evaluated in children separately from adults. No age-adjustment factor is used in this case. The focus on children is considered protective of the higher daily intake rates of soil by children and their lower body weight. For maintaining consistency when evaluating soils, dermal and inhalation exposures are also based on childhood contact rates.

(1) ingestion([mg!yr]/[kg!d]):

$$IFS_{adj} = \frac{ED_c \ x \ IRS_c}{BW_c} + \frac{(ED_r - ED_c) \ x \ IRS_a}{BW_a}$$

(2) skin contact([mg!yr]/[kg!d]:

$$SFS_{adj} = \frac{ED_c \ x \ AF \ x \ SA_c}{BW_c} + \frac{(ED_r - ED_c) \ x \ AF \ x \ SA_a}{BW_a}$$

(3) inhalation ([m^3!yr]/[kg!d]):

$$InhF_{adj} = \frac{ED_c \ x \ IRA_c}{BW_c} + \frac{(ED_r - ED_c) \ x \ IRA_a}{BW_a}$$

Screening Level Equations

The equations used to calculate the screening levels for carcinogenic and non-carcinogenic contaminants are presented in Equations 1 through 8. The screening level equations update RAGS Part B equations. The methodology back calculates a soil, air, or water concentration level from a target risk (for carcinogens) or hazard quotient (for non-carcinogens). For completeness, the soil equations combine risks from ingestion, skin contact, and inhalation simultaneously. The “without dermal” screening values use these equations minus the dermal component of the denominator.

To calculate screening levels for volatile chemicals in soil, a chemical-specific volatilization factor is calculated per Equation 9. Because of its reliance on Henry's law, the VF_s model is applicable only when the contaminant concentration in soil is at or below saturation (i.e. there is no free-phase contaminant present). Soil saturation ("sat") corresponds to the contaminant concentration in soil at which the adsorptive limits of the soil particles and the solubility limits of the available soil moisture have been reached. Above this point, pure liquid-phase or solid-phase contaminant is expected in the soil. If the screening level calculated using VF_s was greater than the calculated sat, the screening level was set equal to the saturation value for liquid contamination, in accordance with *Soil Screening Guidance* (USEPA 1996 a,b). The updated equation for deriving soil saturation is presented in Equation 10.

STANDARD DEFAULT FACTORS

Symbol	Definition (units)	Default	Reference
CSFo	Cancer slope factor oral (mg/kg-d)-1	--	IRIS, HEAST, or NCEA
CSFi	Cancer slope factor inhaled (mg/kg-d)-1	--	IRIS, HEAST, or NCEA
RfDo	Reference dose oral (mg/kg-d)	--	IRIS, HEAST, or NCEA
RfDi	Reference dose inhaled (mg/kg-d)	--	IRIS, HEAST, or NCEA
TR	Target cancer risk	10^{-6}	--
THQ	Target hazard quotient	1	--
BWa	Body weight, adult (kg)	70	RAGS (Part a), EPA 1989 (EPA/540/1-89/002)
BWc	Body weight, child (kg)	15	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
ATc	Averaging time - carcinogens (days)	25550	RAGS(Part a), EPA 1989 (EPA/540/1-89/002)
ATn	Averaging time - noncarcinogens (days)	ED*365	
SAa	Exposed surface area, adult (cm^2/day)	5700	
SAc	Exposed surface area, child (cm^2/day)	2900	
AFa	Adherence factor, adult (mg/cm^2)	0.07	See text
Afw	Adherence factor, adult-work (mg/cm^2)	0.2	See text
AFc	Adherence factor, child (mg/cm^2)	0.2	See text
ABS	Skin absorption (unitless):		
	-- organics	0.1	Dermal Assessment, See text
	--Inorganics	none	Dermal Assessment, See text
IRAa	Inhalation rate - adult (m^3/day)	20	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
IRAc	Inhalation rate - child (m^3/day)	10	RAGS (Part A), EPA 1989 (EPA/540/1-89/002)
IRWa	Drinking water ingestion - adult (L/day	2	RAGS(Part A), EPA 1989 (EPA/540/1-89/002)
IRWc	Drinking water ingestion - child (L/day)	1	
IRSa	Soil ingestion - adult (mg/day)	100	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
IRSc	Soil ingestion - child (mg/day),	200	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
IRSo	Soil ingestion - occupational (mg/day)	50	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
EFr	Exposure frequency - residential (d/y)	350	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
EFo	Exposure frequency - occupational (d/y)	250	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
EDr	Exposure duration - residential (years)	30[a]	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
EDc	Exposure duration - child (years)	6	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
EDo	Exposure duration - occupational (years)	25	Exposure Factors , EPA 1991 (OSWER No. 9285.6-03)
	Age-adjusted factors for carcinogens:		
IFSadj	Ingestion factor, soils ([mg!yr]/[kg!d])	114	RAGS(Part B) , EPA 1991 (OSWER No. 9285.7-01B)
SFSadj	Skin contact factor, soils ([mg!yr]/[kg!d])	340	By analogy to RAGS (Part B)
InhFadj	Inhalation factor ([m^3!yr]/[kg!d])	11	By analogy to RAGS (Part B)
IFWadj	Ingestion factor, water ([l!yr]/[kg!d])	1.1	By analogy to RAGS (Part B)
VFw	Volatilization factor for water (L/m^3)	0.5	RAGS(Part B) , EPA 1991 (OSWER No. 9285.7-01B)
PEF	Particulate emission factor (m^3/kg)	See below	Soil Screening Guidance (EPA 1996a,b)
VFs	Volatilization factor for soil (m^3/kg)	See below	Soil Screening Guidance (EPA 1996a,b)
sat	Soil saturation concentration (mg/kg)	See below	Soil Screening Guidance (EPA 1996a,b)

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Footnote:
[a]Exposure duration for lifetime residents is assumed to be 30 years total. For carcinogens, exposures are combined for children (6 years) and adults (24 years) .

SCREENING LEVEL EQUATIONS

Soil Equations: For soils, equations were based on three exposure routes (ingestion, skin contact, and inhalation).

Equation 1: Combined Exposures to Carcinogenic Contaminants in Residential Soil

$$C(mg/kg) = \frac{TR \times AT_c}{EF_r\left[\left(\frac{IFS_{adj} \text{ x } CSF_o}{10^6 mg/kg}\right) + \left(\frac{SFS_{adj} \times ABS \text{ x } CSF_o}{10^6 mg/kg}\right) + \left(\frac{Inh_{adj} \text{ x } CSF_i}{VF_s\,*}\right)\right]}$$

Equation 2: Combined Exposures to Noncarcinogenic Contaminants in Residential Soil

$$C(mg/kg) = \frac{THQ \times BW_c \times AT_n}{EF_r \times ED_c\left[\left(\frac{1}{RfD_o}\right) \times \left(\frac{IRS_c}{10^6 mg/kg}\right) + \left(\frac{1 \times SA_c \times AF \times ABS}{RfD_o \times 10^6 mg/kg}\right) + \left(\frac{1}{RfD_i} \times \frac{IRA_c}{VF_s\,*}\right)\right]}$$

Equation 3: Combined Exposures to Carcinogenic Contaminants in Industrial Soil

$$C(mg/kg) = \frac{TR \times BW_a \times AT_c}{EF_o \times ED_o\left[\left(\frac{IRS_o}{10^6 mg/kg}\right) + \left(\frac{SA_a \times AF \times ABS \text{ x } CSF_o}{10^6 mg/kg}\right) + \left(\frac{IRA_a \text{ x } CSF_i}{VF_s\,*}\right)\right]}$$

Equation 4: Combined Exposures to Noncarcinogenic Contaminants in Industrial Soil

$$C(mg/kg) = \frac{THQ \times BW_a \times AT_n}{EF_o \times ED_o\left[\left(\frac{1}{RfD_o}\right) \times \left(\frac{IRS_o}{10^6 mg/kg}\right) + \left(\frac{1 \times SA_a \times AF \times ABS}{RfD_o \times 10^6 mg/kg}\right) + \left(\frac{1}{RfD_i} \times \frac{IRA_a}{VF_s\,*}\right)\right]}$$

Footnote:

* Use VF_s for volatile chemicals (defined as having a Henry's Law Constant [atm-m^3/mol] greater than 10^{-5} and a molecular weight less than 200 grams/mol) or PEF for non-volatile chemicals.

Tap Water Equations:

Equation 5: Ingestion and Inhalation Exposures to Carcinogenic Contaminants in Water

$$C(ug/L) \ = \ \frac{TR \ x \ AT_c \ x \ 1000ug/mg}{EF_r \ [(IFW_{adj} \ x \ CSF_o) \ + \ (VF_w \ x \ InhF_{adj} \ x \ CSF_i)]}$$

Equation 6: Ingestion and Inhalation Exposures to Noncarcinogenic Contaminants in Water

$$C(ug/L) \ = \ \frac{THQ \ x \ BW_a \ x \ AT_n \ x \ 1000ug/mg}{EF_r \ x \ ED_r \ [(\frac{IRW_a}{RfD_o}) \ + \ (\frac{VF_w \ x \ IRA_a}{RfD_i})]}$$

<u>Air Equations</u>:

Equation 7: Inhalation Exposures to Carcinogenic Contaminants in Air

$$C(ug/m^3) \ = \ \frac{TR \ x \ AT_c \ x \ 1000ug/mg}{EF_r \ x \ InhF_{adj} \ x \ CSF_i}$$

Equation 8: Inhalation Exposures to Noncarcinogenic Contaminants in Air

$$C(ug/m^3) \ = \ \frac{THQ \ x \ RfD_i \ x \ BW_a \ x \ AT_n \ x \ 1000ug/mg}{EF_r \ x \ ED_r \ x \ IRA_a}$$

SOIL-TO-AIR VOLATILIZATION FACTOR (VF_s)

Equation 9: Derivation of the Volatilization Factor

$$VF_s(m^3/kg) = (Q/C) \ x \ \frac{(3.14 \ x \ D_A \ x \ T)^{1/2}}{(2 \ x \ \rho_b \ x \ D_A)} \ x \ 10^{-4}(m^2/cm^2)$$

where:

$$D_A = \frac{[(\Theta_a^{10/3} D_i H' + \Theta_w^{10/3} D_w)/n^2]}{\rho_B K_d + \Theta_w + \Theta_a H'}$$

Parameter	Definition (units)	Default
VF_s	Volatilization factor (m^3/kg)	--
D_A	Apparent diffusivity (cm^2/s)	--
Q/C	Inverse of the mean conc. at the center of a 0.5-acre square source (g/m^2-s per kg/m^3)	68.81
T	Exposure interval (s)	9.5×10^8
ρ_b	Dry soil bulk density (g/cm^3)	1.5
Θ_a	Air filled soil porosity (L_{air}/L_{soil})	0.28 or n-Θ_w
n	Total soil porosity (L_{pore}/L_{soil})	0.43 or 1 - (ρ_b/ρ_s)
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.15
ρ_s	Soil particle density (g/cm^3)	2.65
Di	Diffusivity in air (cm^2/s)	Chemical-specific
H	Henry's Law constant (atm-m^3/mol)	Chemical-specific
H'	Dimensionless Henry's Law constant	Calculated from H by multiplying by 41 (USEPA 1991a)
D_w	Diffusivity in water (cm^2/s)	Chemical-specific
K_d	Soil-water partition coefficient (cm^3/g) = $K_{oc}f_{oc}$	Chemical-specific
K_{oc}	Soil organic carbon-water partition coefficient (cm^3/g)	Chemical-specific
f_{oc}	Fraction organic carbon in soil (g/g)	0.006 (0.6%)

SOIL SATURATION CONCENTRATION (sat)

Equation 10: Derivation of the Soil Saturation Limit

$$sat = \frac{S}{\rho_b} (K_d \rho_b + \Theta_w + H' \Theta_a)$$

Parameter	Definition (units)	Default
sat	Soil saturation concentration (mg/kg)	--
S	Solubility in water (mg/L-water)	Chemical-specific
ρ_b	Dry soil bulk density (kg/L)	1.5
n	Total soil porosity (L_{pore}/L_{soil})	0.43 or 1 - (ρ_b/ρ_s)
ρ_s	Soil particle density (kg/L)	2.65
K_d	Soil-water partition coefficient (L/kg)	K_{oc} x f_{oc} (chemical-specific)
k_{oc}	Soil organic carbon/water partition coefficient (L/kg)	Chemical-specific
f_{oc}	Fraction organic carbon content of soil (g/g)	0.006 or site-specific
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.15
Θ_a	Air filled soil porosity (L_{air}/L_{soil})	0.28 or n-Θ_w
w	Average soil moisture content (kg_{water}/kg_{soil} or L_{water}/kg_{soil})	0.1
H	Henry's Law constant (atm-m^3/mol)	Chemical-specific
H'	Dimensionless Henry's Law constant	H x 41, where 41 is a units conversion factor

SOIL-TO-AIR PARTICULATE EMISSION FACTOR (PEF)

Equation 11: Derivation of the Particulate Emission Factor

$$PEF(m^3/kg) = Q/C \ x \ \frac{3600 s/h}{0.036 \ x \ (1-V) \ x \ (U_m/U_t)^3 \ x \ F(x)}$$

Parameter	Definition (units)	Default
PEF	Particulate emission factor (m^3/kg)	1. 316 x 10^9
Q/C	Inverse of the mean concentration at the center of a 0.5-acre-square source (g/m^2-s per kg/m^3)	90.80
V	Fraction of vegetative cover (unitless)	0.5
U_m	Mean annual windspeed (m/s)	4.69
U_t	Equivalent threshold value of windspeed at 7 m (m/s)	11.32
F(x)	Function dependent on U_m/U_t derived using Cowherd (1985) (unitless)	0.194

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